US009458789B2

(12) **United States Patent**
Lucido et al.

(10) **Patent No.: US 9,458,789 B2**
(45) **Date of Patent: Oct. 4, 2016**

(54) **MISSED FUEL INJECTION DIAGNOSTIC SYSTEMS AND METHODS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 254 days.

(21) Appl. No.: **14/231,807**

(22) Filed: **Apr. 1, 2014**

(65) **Prior Publication Data**

US 2015/0275807 A1 Oct. 1, 2015

(51) **Int. Cl.**

F02D 41/30	(2006.01)
F02D 41/20	(2006.01)
F02D 41/22	(2006.01)
F02D 41/40	(2006.01)

(52) **U.S. Cl.**

CPC ***F02D 41/3005*** (2013.01); ***F02D 41/20*** (2013.01); ***F02D 41/221*** (2013.01); *F02D 41/402* (2013.01); *F02D 2041/2055* (2013.01); *F02D 2200/0602* (2013.01)

(58) **Field of Classification Search**

CPC F02D 41/20; F02D 41/03; F02D 41/221; F02D 41/222; F02D 2041/2003; F02D 2041/2006; F02D 2041/2051; F02D 2041/2005; F02D 2041/2058

USPC ..... 123/279, 490, 499, 198 D; 701/107, 114

See application file for complete search history.

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U.S. Appl. No. 14/242,058, filed Apr. 1, 2014, Shibata et al.
U.S. Appl. No. 14/242,247, filed Apr. 1, 2014, Shibata et al.

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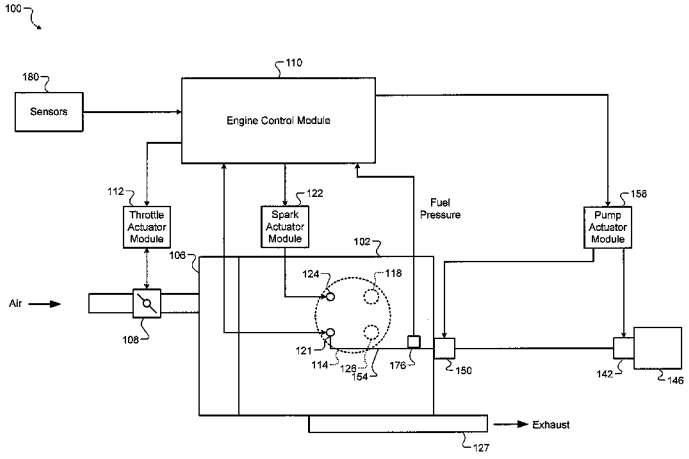
(57) **ABSTRACT**

An injector driver module applies power to a fuel injector of an engine for a fuel injection event. A voltage measuring module measures first and second voltages at first and second electrical connectors of the fuel injector. A parameter determination module determines a maximum value based on a first difference between the first and second voltages, determines a minimum value based on the first difference between the first and second voltages, and determines a second difference between the maximum and minimum values. A diagnostic module, based on the second difference between the maximum and minimum values, indicates whether the fuel injector injected fuel in response to the application of power.

19 Claims, 7 Drawing Sheets



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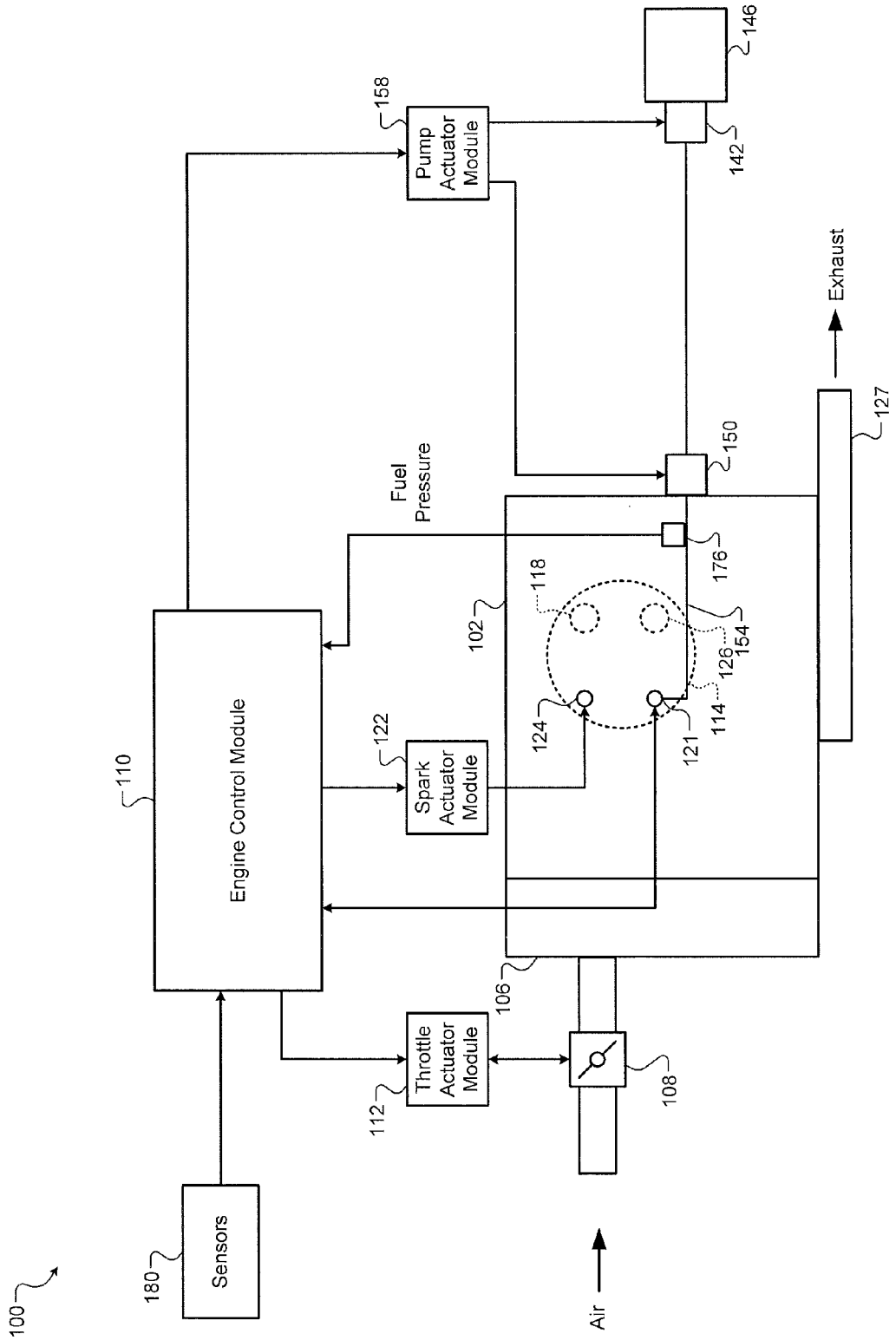
100
180
Sensors
110
Engine Control Module
112
Throttle Actuator Module
108
Air
106
122
Spark Actuator Module
124
121
114
126
154
118
102
176
Fuel Pressure
150
127
Exhaust
158
Pump Actuator Module
142
146

FIG. 1

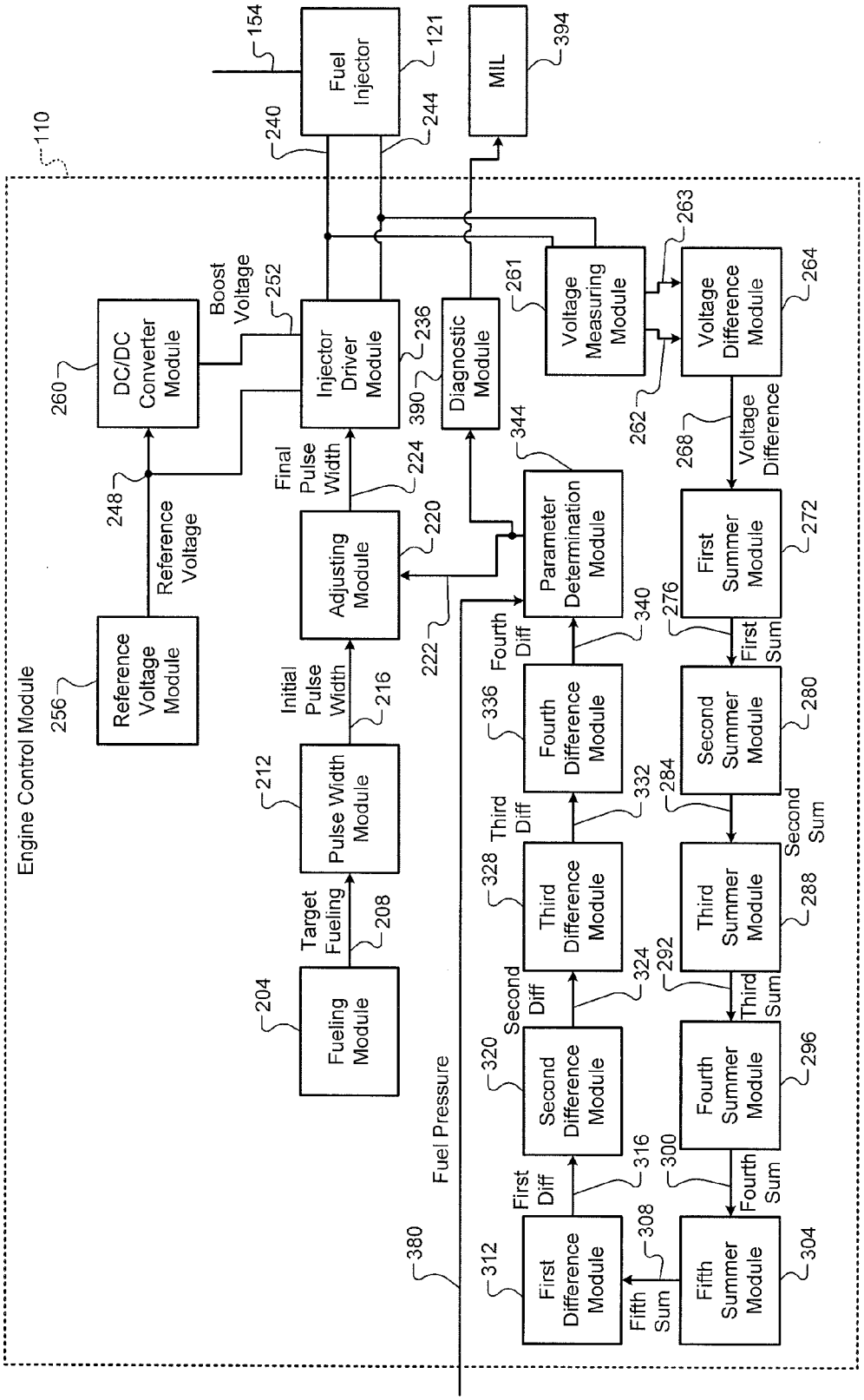
Engine Control Module
110
Fuel Injector
121
154
240
244
MIL
394
DC/DC Converter Module
260
Boost Voltage
252
Injector Driver Module
236
Diagnostic Module
390
261
Voltage Measuring Module
263
Voltage Difference Module
264
262
268
Voltage Difference
Reference Voltage Module
256
248
Reference Voltage
Adjusting Module
220
Final Pulse Width
224
Parameter Determination Module
344
Initial Pulse Width
216
222
Pulse Width Module
212
Target Fueling
208
Fueling Module
204
Fuel Pressure
380
Fourth Diff
340
Fourth Difference Module
336
First Summer Module
272
276
First Sum
Third Diff
332
Third Difference Module
328
Second Summer Module
280
284
Second Sum
Second Diff
324
Second Difference Module
320
Third Summer Module
288
292
Third Sum
First Diff
316
First Difference Module
312
Fourth Summer Module
296
300
Fourth Sum
Fifth Sum
308
Fifth Summer Module
304

FIG. 2

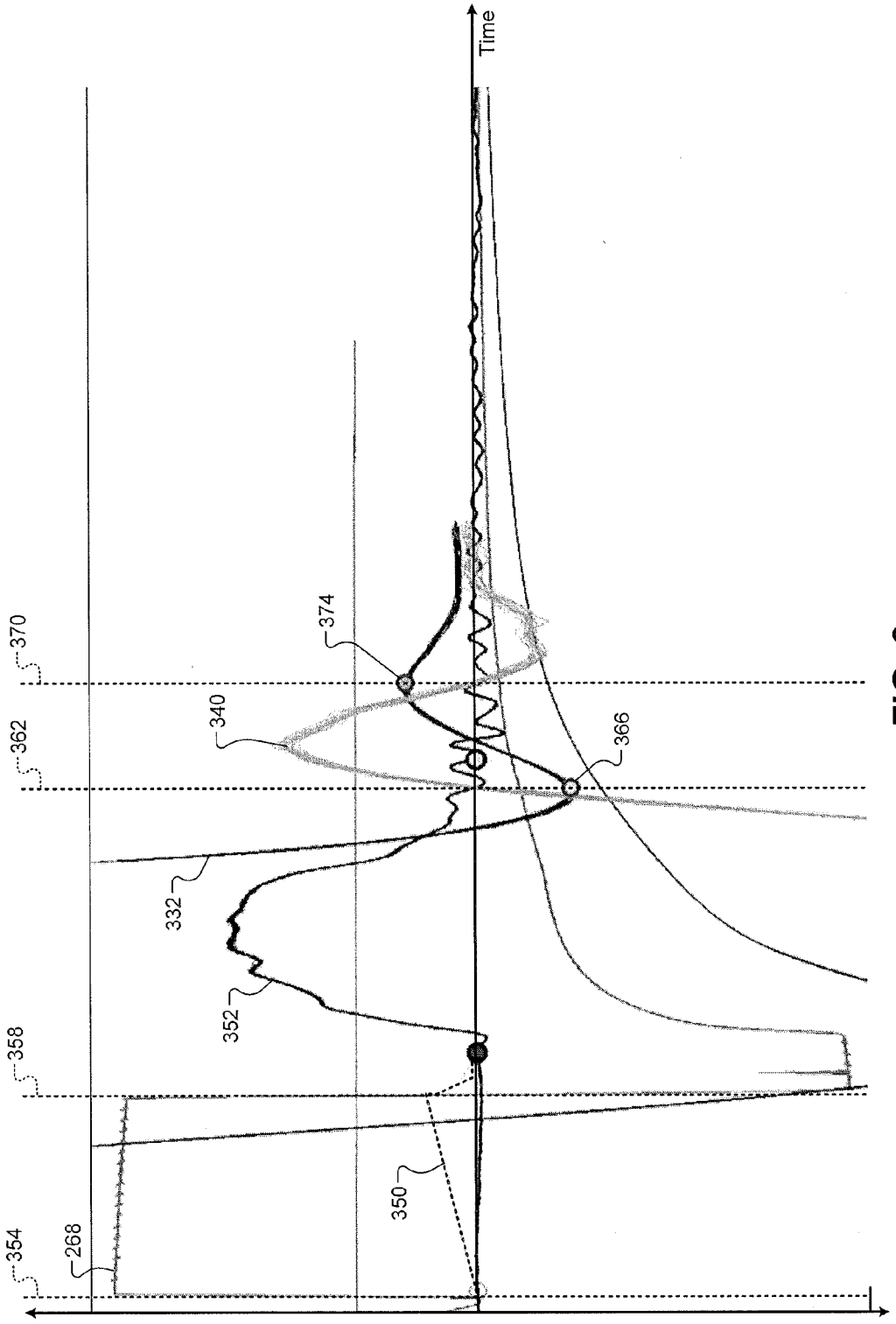

FIG. 3

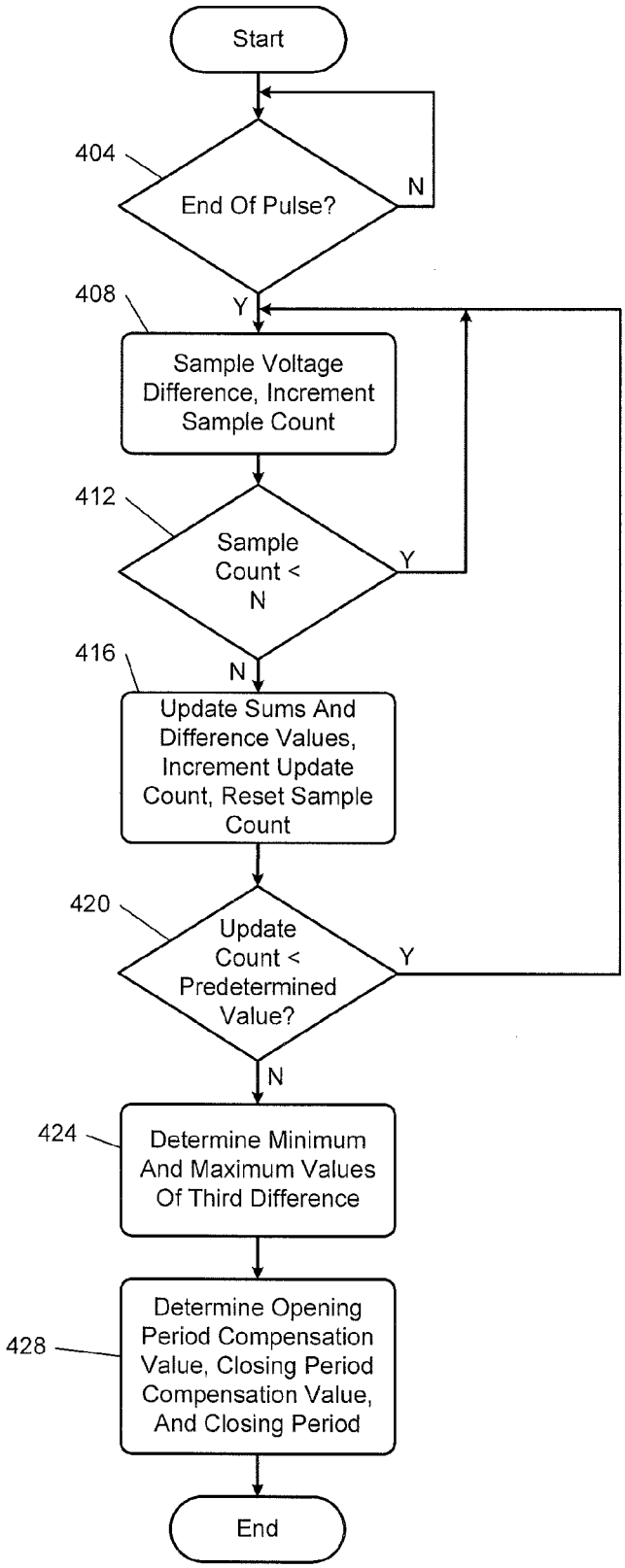
Start
404
End Of Pulse?
N
Y
408
Sample Voltage Difference, Increment Sample Count
412
Sample Count < N
Y
N
416
Update Sums And Difference Values, Increment Update Count, Reset Sample Count
420
Update Count < Predetermined Value?
Y
N
424
Determine Minimum And Maximum Values Of Third Difference
428
Determine Opening Period Compensation Value, Closing Period Compensation Value, And Closing Period
End

FIG. 4

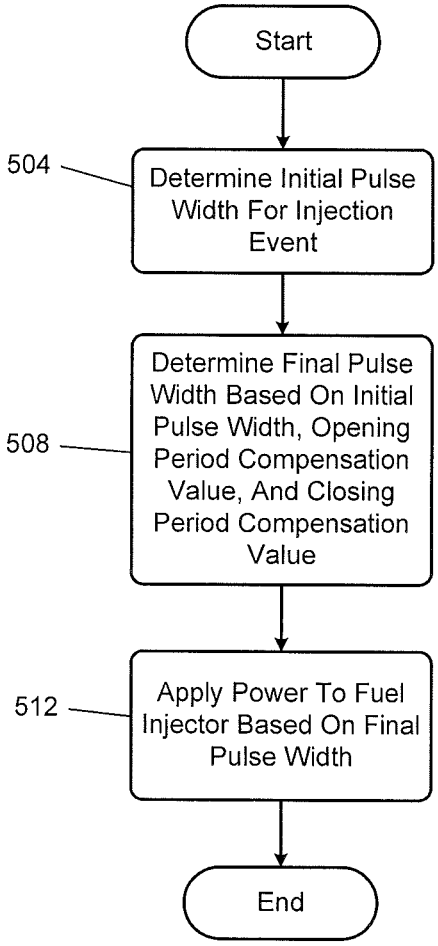
Start
504
Determine Initial Pulse Width For Injection Event
508
Determine Final Pulse Width Based On Initial Pulse Width, Opening Period Compensation Value, And Closing Period Compensation Value
512
Apply Power To Fuel Injector Based On Final Pulse Width
End

FIG. 5

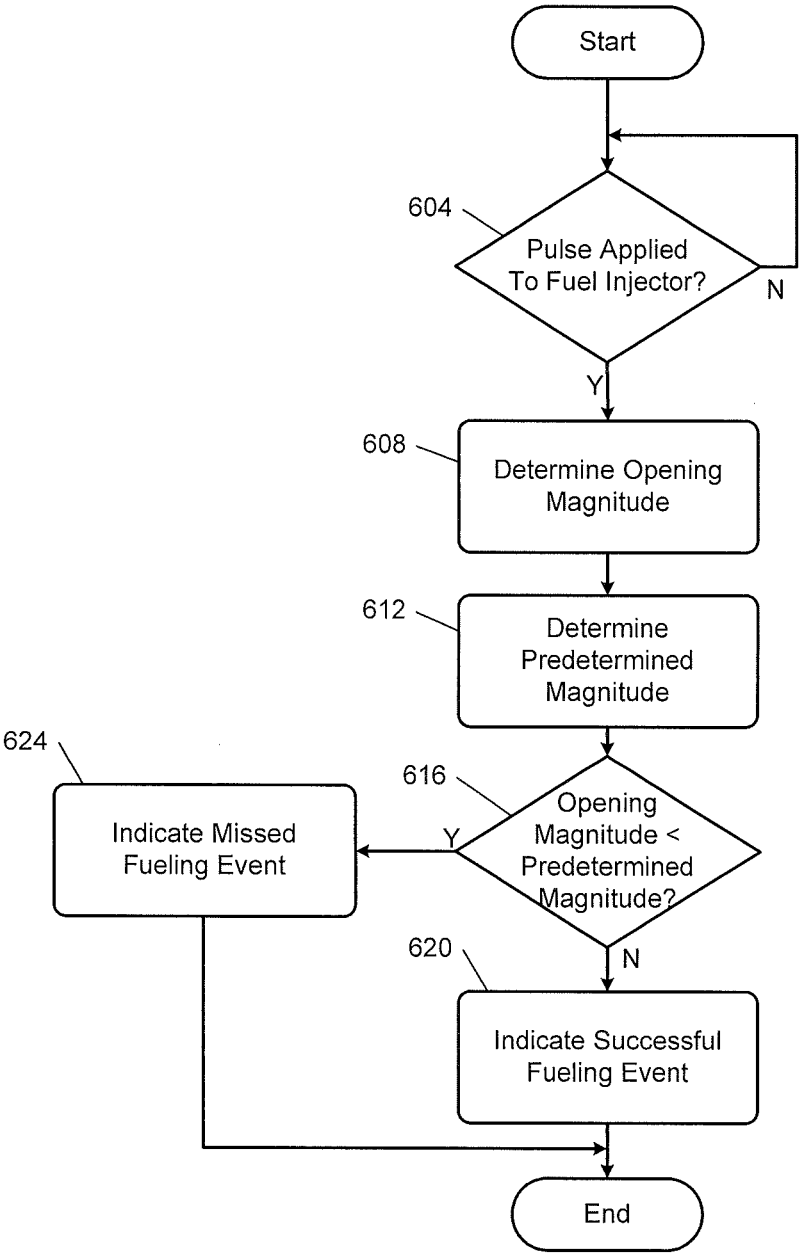
Start
604
Pulse Applied To Fuel Injector?
N
Y
608
Determine Opening Magnitude
612
Determine Predetermined Magnitude
624
616
Indicate Missed Fueling Event
Y
Opening Magnitude < Predetermined Magnitude?
620
N
Indicate Successful Fueling Event
End

FIG. 6

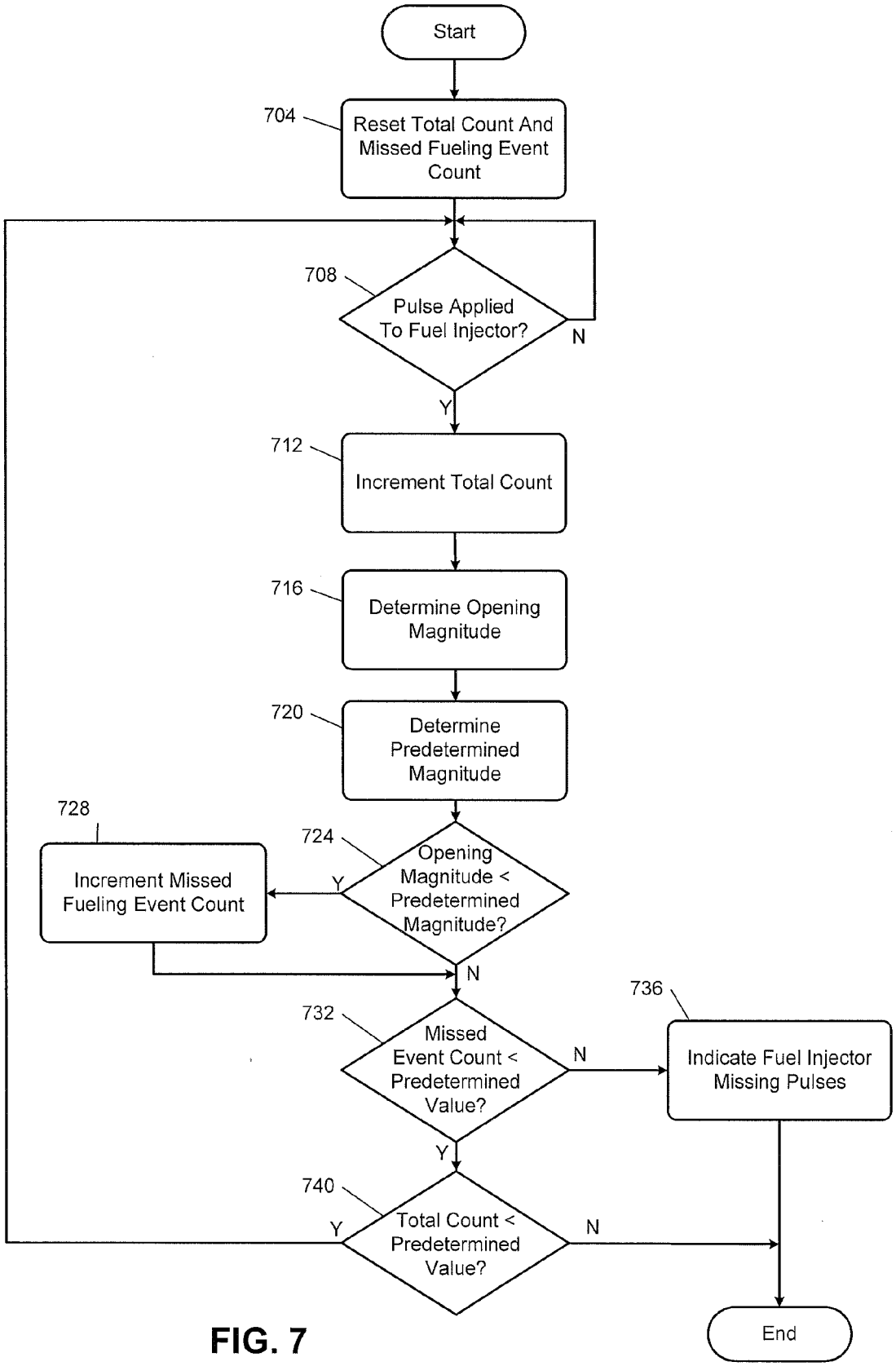
Start
704
Reset Total Count And Missed Fueling Event Count
708
Pulse Applied To Fuel Injector?
N
Y
712
Increment Total Count
716
Determine Opening Magnitude
720
Determine Predetermined Magnitude
728
724
Opening Magnitude < Predetermined Magnitude?
Y
Increment Missed Fueling Event Count
N
736
732
Missed Event Count < Predetermined Value?
N
Indicate Fuel Injector Missing Pulses
Y
740
Total Count < Predetermined Value?
Y
N
End

FIG. 7

MISSED FUEL INJECTION DIAGNOSTIC SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. patent application Ser. No. 14/242,001 filed on Apr. 1, 2014, Ser. No. 14/242,058 filed on Apr. 1, 2014 and Ser. No. 14/242,247 filed on Apr. 1, 2014. The entire disclosure of the above applications are incorporated herein by reference.

FIELD

The present application relates to internal combustion engines and more particularly to fuel injector control systems and methods for engines.

BACKGROUND

The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Air is drawn into an engine through an intake manifold. A throttle valve and/or engine valve timing controls airflow into the engine. The air mixes with fuel from one or more fuel injectors to form an air/fuel mixture. The air/fuel mixture is combusted within one or more cylinders of the engine. Combustion of the air/fuel mixture may be initiated by, for example, spark provided by a spark plug.

Combustion of the air/fuel mixture produces torque and exhaust gas. Torque is generated via heat release and expansion during combustion of the air/fuel mixture. The engine transfers torque to a transmission via a crankshaft, and the transmission transfers torque to one or more wheels via a driveline. The exhaust gas is expelled from the cylinders to an exhaust system.

An engine control module (ECM) controls the torque output of the engine. The ECM may control the torque output of the engine based on driver inputs. The driver inputs may include, for example, accelerator pedal position, brake pedal position, and/or one or more other suitable driver inputs.

SUMMARY

A fuel control system for a vehicle includes: an injector driver module that applies power to a fuel injector of an engine for a fuel injection event; a voltage measuring module that measures first and second voltages at first and second electrical connectors of the fuel injector; a parameter determination module that determines a maximum value based on a first difference between the first and second voltages, that determines a minimum value based on the first difference between the first and second voltages, and that determines a second difference between the maximum and minimum values; and a diagnostic module that, based on the second difference between the maximum and minimum values, indicates whether the fuel injector injected fuel in response to the application of power.

In further features, the diagnostic module determines a predetermined value based on a fuel pressure of the fuel injection event and determines whether the fuel injector injected fuel in response to the application of power based on a comparison of the predetermined value with the second difference between the maximum and minimum values.

In still further features, the diagnostic module indicates that the fuel injector did not inject fuel in response to the application of power when the second difference between the maximum and minimum values is less than the predetermined value.

In yet further features, the diagnostic module indicates that the fuel injector injected fuel in response to the application of power when the second difference between the maximum and minimum values is greater than the predetermined value.

In further features, the diagnostic module selectively illuminates a malfunction indicator lamp (MIL) when the fuel injector did not inject fuel in response to the application of power.

In still further features, the diagnostic module stores a predetermined diagnostic trouble code (DTC) in memory when the fuel injector did not inject fuel in response to the application of power.

In further features: a first summer module that determines a first sum of (i) the first difference between the first and second voltages and (ii) N previous values of the first difference between the first and second voltages, wherein N is an integer greater than or equal to one; a second summer module that determines a second sum of (i) the first sum and (ii) M previous values of the first sum, wherein M is an integer greater than or equal to one; a first difference module that determines a third difference between (i) the second sum and (ii) a previous value of the second sum; a second difference module that determines a fourth difference between (i) the third difference and (ii) a previous value of the third difference; a third difference module that determines a fifth difference between (i) the fourth difference and (ii) a previous value of the fourth difference; and a fourth difference module that determines a sixth difference between (i) the fifth difference and (ii) a previous value of the fifth difference, wherein the parameter determination module determines the maximum value of the third difference and the minimum value of the third difference and determines the second difference between the maximum and minimum values of the third difference.

In still further features, the parameter determination module determines the minimum value of the third difference based on a first zero-crossing of the fourth difference.

In yet further features, the parameter determination module determines the maximum value of the third difference based on a second zero-crossing of the fourth difference.

In further features, the injector driver module applies power to the fuel injector for a second fuel injection event of the fuel injector based on the second difference between the maximum and minimum values.

In a feature, a control system for a vehicle includes: a driver module that applies power to an actuator including a solenoid for an opening event; a voltage measuring module that measures first and second voltages at first and second electrical connectors of the actuator; a parameter determination module that determines a maximum value based on a first difference between the first and second voltages, that determines a minimum value based on the first difference between the first and second voltages, and that determines a second difference between the maximum and minimum values; and a diagnostic module that, based on the second difference between the maximum and minimum values, indicates whether the solenoid opened in response to the application of power.

In another feature, a fuel control method for a vehicle includes: applying power to a fuel injector of an engine for a fuel injection event; measuring first and second voltages at first and second electrical connectors of the fuel injector; determining a maximum value based on a first difference between the first and second voltages; determining a minimum value based on the first difference between the first and second voltages; determining a second difference between the maximum and minimum values; and, based on the second difference between the maximum and minimum values, indicating whether the fuel injector injected fuel in response to the application of power.

In further features, the fuel control method further includes: determining a predetermined value based on a fuel pressure of the fuel injection event; and determining whether the fuel injector injected fuel in response to the application of power based on a comparison of the predetermined value with the second difference between the maximum and minimum values.

In still further features, the fuel control method further includes: indicating that the fuel injector did not inject fuel in response to the application of power when the second difference between the maximum and minimum values is less than the predetermined value.

In yet further features, the fuel control method further includes: indicating that the fuel injector injected fuel in response to the application of power when the second difference between the maximum and minimum values is greater than the predetermined value.

In further features, the fuel control method further includes: selectively illuminating a malfunction indicator lamp (MIL) when the fuel injector did not inject fuel in response to the application of power.

In still further features, the fuel control method further includes: storing a predetermined diagnostic trouble code (DTC) in memory when the fuel injector did not inject fuel in response to the application of power.

In yet further features, the fuel control method further includes: determining a first sum of (i) the first difference between the first and second voltages and (ii) N previous values of the first difference between the first and second voltages, wherein N is an integer greater than or equal to one; determining a second sum of (i) the first sum and (ii) M previous values of the first sum, wherein M is an integer greater than or equal to one; determining a third difference between (i) the second sum and (ii) a previous value of the second sum; determining a fourth difference between (i) the third difference and (ii) a previous value of the third difference; determining a fifth difference between (i) the fourth difference and (ii) a previous value of the fourth difference; determining a sixth difference between (i) the fifth difference and (ii) a previous value of the fifth difference; determining the maximum value of the third difference and the minimum value of the third difference; and determining the second difference between the maximum and minimum values of the third difference.

In further features, the fuel control method further includes: determining the minimum value of the third difference based on a first zero-crossing of the fourth difference.

In yet further features, the fuel control method further includes: determining the maximum value of the third difference based on a second zero-crossing of the fourth difference.

In still further features, the fuel control method further includes: applying power to the fuel injector for a second fuel injection event of the fuel injector based on the second difference between the maximum and minimum values.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is a functional block diagram of an example direct injection engine system;

FIG. **2** is a functional block diagram of an example fuel control system including a portion of an engine control module;

FIG. **3** is an example graph of voltage and current of a fuel injector, and various parameters determined based on the voltage for an injection event;

FIG. **4** is a flowchart depicting an example method of determining various parameters for a fuel injection event of a fuel injector;

FIG. **5** is a flowchart depicting an example method of controlling fueling for a fuel injection event of a fuel injector;

FIG. **6** is a flowchart depicting an example method of determining whether a fuel injector injected fuel for a fuel injection event; and

FIG. **7** is a flowchart depicting an example method of diagnosing a fault associated with a fuel injector.

In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

An engine combusts a mixture of air and fuel within cylinders to generate drive torque. A throttle valve regulates airflow into the engine. Fuel is injected by fuel injectors. Spark plugs may generate spark within the cylinders to initiate combustion. Intake and exhaust valves of a cylinder may be controlled to regulate flow into and out of the cylinder.

The fuel injectors receive fuel from a fuel rail. A high pressure fuel pump receives fuel from a low pressure fuel pump and pressurizes the fuel within the fuel rail. The low pressure fuel pump draws fuel from a fuel tank and provides fuel to the high pressure fuel pump. The fuel injectors inject fuel directly into the cylinders of the engine.

Different fuel injectors, however, may have different opening and closing characteristics. For example, fuel injectors from different fuel injector manufacturers may have different opening and closing characteristics. Even fuel injectors from the same fuel injector manufacturer, however, may have different opening and closing characteristics. Example opening and closing characteristics include, for example, opening period and closing period. The opening period of a fuel injector may refer to the period between a first time when power is applied to the fuel injector to open the fuel injector and a second time when the fuel injector actually opens in response to the application of power. The closing period of a fuel injector may refer to the period between a first time when power is removed from the fuel injector to close the fuel injector and a second time when the fuel injector reaches a fully closed state in response to the removal of power.

The present application involves determining various parameters based on a difference between voltages at first and second electrical conductors of a fuel injector. For example, an engine control module (ECM) may determine first, second, third, and fourth order derivatives of the difference. Additionally or alternatively, the ECM may determine parameters that track the first, second, third, and fourth derivatives of the difference, for example, using a plurality of sums and differences. The ECM also determines whether the fuel injector injected fuel for a fuel injection event based on one or more of the parameters.

Referring now to FIG. **1**, a functional block diagram of an example engine system **100** for a vehicle is presented. The engine system **100** includes an engine **102** that combusts an air/fuel mixture to produce drive torque for a vehicle. While the engine **102** will be discussed as a spark ignition direct injection (SIDI) engine, the engine **102** may include another type of engine. One or more electric motors and/or motor generator units (MGUs) may be provided with the engine **102**.

Air is drawn into an intake manifold **106** through a throttle valve **108**. The throttle valve **108** may vary airflow into the intake manifold **106**. For example only, the throttle valve **108** may include a butterfly valve having a rotatable blade. An engine control module (ECM) **110** controls a throttle actuator module **112** (e.g., an electronic throttle controller or ETC), and the throttle actuator module **112** controls opening of the throttle valve **108**.

Air from the intake manifold **106** is drawn into cylinders of the engine **102**. While the engine **102** may include more than one cylinder, only a single representative cylinder **114** is shown. Air from the intake manifold **106** is drawn into the cylinder **114** through an intake valve **118**. One or more intake valves may be provided with each cylinder.

The ECM **110** controls fuel injection into the cylinder **114** via a fuel injector **121**. The fuel injector **121** injects fuel, such as gasoline, directly into the cylinder **114**. The fuel injector **121** is a solenoid type, direct injection fuel injector. Solenoid type, direct injection fuel injectors are different than port fuel injection (PFI) injectors and piezo electric fuel injectors. The ECM **110** may control fuel injection to achieve a desired air/fuel ratio, such as a stoichiometric air/fuel ratio. A fuel injector may be provided for each cylinder.

The injected fuel mixes with air and creates an air/fuel mixture in the cylinder **114**. Based upon a signal from the ECM **110**, a spark actuator module **122** may energize a spark plug **124** in the cylinder **114**. A spark plug may be provided for each cylinder. Spark generated by the spark plug **124** ignites the air/fuel mixture.

The engine **102** may operate using a four-stroke cycle or another suitable operating cycle. The four strokes, described below, may be referred to as the intake stroke, the compression stroke, the combustion stroke, and the exhaust stroke. During each revolution of a crankshaft (not shown), two of the four strokes occur within the cylinder **114**. Therefore, two crankshaft revolutions are necessary for the cylinders to experience all four of the strokes.

During the intake stroke, air from the intake manifold **106** is drawn into the cylinder **114** through the intake valve **118**. Fuel injected by the fuel injector **121** mixes with air and creates an air/fuel mixture in the cylinder **114**. One or more fuel injections may be performed during a combustion cycle. During the compression stroke, a piston (not shown) within the cylinder **114** compresses the air/fuel mixture. During the combustion stroke, combustion of the air/fuel mixture drives the piston, thereby driving the crankshaft. During the exhaust stroke, the byproducts of combustion are expelled through an exhaust valve **126** to an exhaust system **127**.

A low pressure fuel pump **142** draws fuel from a fuel tank **146** and provides fuel at low pressures to a high pressure fuel pump **150**. While only the fuel tank **146** is shown, more than one fuel tank **146** may be implemented. The high pressure fuel pump **150** further pressurizes the fuel within a fuel rail **154**. The fuel injectors of the engine **102**, including the fuel injector **121**, receive fuel via the fuel rail **154**. Low pressures provided by the low pressure fuel pump **142** are described relative to high pressures provided by the high pressure fuel pump **150**.

The low pressure fuel pump **142** may be an electrically driven pump. The high pressure fuel pump **150** may be a variable output pump that is mechanically driven by the engine **102**. A pump actuator module **158** may control output of the high pressure fuel pump **150** based on signals from the ECM **110**. The pump actuator module **158** may also control operation (e.g., ON/OFF state) of the low pressure fuel pump **142**.

The engine system **100** includes a fuel pressure sensor **176**. The fuel pressure sensor **176** measures a pressure of the fuel in the fuel rail **154**. The engine system **100** may include one or more other sensors **180**. For example, the other sensors **180** may include one or more other fuel pressure sensors, a mass air flowrate (MAF) sensor, a manifold absolute pressure (MAP) sensor, an intake air temperature (IAT) sensor, a coolant temperature sensor, an oil temperature sensor, a crankshaft position sensor, and/or one or more other suitable sensors.

Referring now to FIG. **2**, a functional block diagram of an example fuel control system including an example portion of the ECM **110** is presented. A fueling module **204** determines target fuel injection parameters **208** for a fuel injection event of the fuel injector **121**. For example, the fueling module **204** may determine a target mass of fuel for the fuel injection event and a target starting timing for the fuel injection event. The fueling module **204** may determine the target mass of fuel, for example, based on a target air/fuel ratio (e.g., stoichiometry) and an expected mass of air within the cylinder **114** for the fuel injection event. One or more fuel injection events may be performed during a combustion cycle of the cylinder **114**.

A pulse width module **212** determines an initial (fuel injection) pulse width **216** for the fuel injection event based on the target mass of fuel. The pulse width module **212** may determine the initial pulse width **216** further based on pressure of the fuel within the fuel rail **154** and/or one or more other parameters. The initial pulse width **216** corresponds to a period to apply power to the fuel injector **121** during the fuel injection event to cause the fuel injector **121** to inject the target mass of fuel under the operating conditions.

Different fuel injectors, however, may have different closing periods, opening periods, opening magnitudes, and other characteristics. The closing period of a fuel injector may refer to the period between: a first time when power is removed from the fuel injector to close the fuel injector; and a second time when the fuel injector actually becomes closed and stops injecting fuel. Fuel injectors with longer closing periods will inject more fuel than fuel injectors with shorter closing periods despite all of the fuel injectors being controlled to inject the same amount of fuel.

The opening period of a fuel injector may refer to the period between: a first time when power is applied to the fuel injector to open the fuel injector; and a second time when the fuel injector actually becomes open and begins injecting

fuel. Fuel injectors with longer opening periods will inject less fuel than fuel injectors with shorter opening periods despite all of the fuel injectors being controlled to inject the same amount of fuel. The opening magnitude of a fuel injector may correspond to how much the fuel injector opens for a fuel injection event.

An adjusting module **220** adjusts the initial pulse width **216** based on one or more injector parameters **222** determined for the fuel injector **121** to produce a final pulse width **224**. The adjustment of the initial pulse width **216** may include lengthening or shortening the initial pulse width **216** to determine the final pulse width **224**, such as by advancing or retarding a beginning of the pulse and/or advancing or retarding an ending of the pulse. Determination of the final pulse width **224** and the injector parameters **222** is described in detail below.

An injector driver module **236** determines a target current profile (not shown) based on the final pulse width **224**. The injector driver module **236** applies high and low voltages to first and second electrical connectors of the fuel injector **121** via high and low side lines **240** and **244** to achieve the target current profile through the fuel injector **121** for the fuel injection event.

The injector driver module **236** may generate the high and low voltages using reference and boost voltages **248** and **252**. The reference and boost voltages **248** and **252** may be direct current (DC) voltages. A reference voltage module **256** provides the reference voltage **248**, for example, based on a voltage of a battery (not shown) of the vehicle. A DC/DC converter module **260** boosts (increases) the reference voltage **248** to generate the boost voltage **252**.

A voltage measuring module **261** measures the high voltage at the first electrical connector of the fuel injector **121** and generates a high side voltage **262** based on the voltage at the first electrical conductor. The voltage measuring module **261** also measures the low voltage at the second electrical connector of the fuel injector **121** and generates a low side voltage **263** based on the voltage at the second electrical conductor. The voltage measuring module **261** measures the high and low voltages relative to a ground reference potential.

A voltage difference module **264** generates a voltage difference **268** based on a difference between the low side voltage **263** and the high side voltage **262**. For example, the voltage difference module **264** may set the voltage difference **268** equal to the low side voltage **263** minus the high side voltage **262**. For another example, the voltage difference module **264** may set the voltage difference **268** equal to the high side voltage **262** minus the low side voltage **263**. The voltage difference module **264** samples the low side voltage **263** and the high side voltage **262** and generates values of the voltage difference **268** based on a predetermined sampling rate. A filter, such as a low pass filter (LPF) or another suitable type of filter, may be implemented to filter the voltage difference **268**. An analog to digital converter (ADC) may also be implemented such that the voltage difference **268** includes corresponding digital values.

A first summer module **272** determines a first sum **276** by summing the last N values of the voltage difference **268**. N is an integer greater than one. For example only, N may be 8 or another suitable value. The first summer module **272** updates the first sum **276** every N sampling periods such that the first sum **276** is updated each time that N new values of the voltage difference **268** have been received.

A second summer module **280** determines a second sum **284** by summing the last M values of the first sum **276**. M is an integer greater than one. For example only, M may be 10 or another suitable value. The second summer module **280** updates the second sum **284** each time the first sum **276** is updated.

A third summer module **288** determines a third sum **292** by summing the last M values of the second sum **284**. The third summer module **288** updates the third sum **292** each time the second sum **284** is updated. A fourth summer module **296** determines a fourth sum **300** by summing the last M values of the third sum **292**. The fourth summer module **296** updates the fourth sum **300** each time the third sum **292** is updated. A fifth summer module **304** determines a fifth sum **308** by summing the last M values of the fourth sum **300**. The fifth summer module **304** updates the fifth sum **308** each time the fourth sum **300** is updated. While the example of calculating the first-fifth sums **276**, **284**, **292**, **300**, and **308** is shown and discussed, two or more sums may be determined, and a greater or lesser number of summer modules may be implemented. The first summer module **272** reduces sampling errors and jitter and also reduces the number of later computations necessary. The other summer modules provide shape preserving filters. Also, while the second-fifth summer modules are each discussed as using M values, one or more of the second-fifth summer modules may use a different number of previous values.

A first difference module **312** determines a first difference **316** based on a difference between the fifth sum **308** and a previous (e.g., last) value of the fifth sum **308**. A second difference module **320** determines a second difference **324** based on a difference between the first difference **316** and a previous (e.g., last) value of the first difference **316**.

A third difference module **328** determines a third difference **332** based on a difference between the second difference **324** and a previous (e.g., last) value of the second difference **324**. A fourth difference module **336** determines a fourth difference **340** based on a difference between the third difference **332** and a previous (e.g., last) value of the third difference **332**.

The first difference **316** corresponds to and has the same shape as a first derivative (d/dt) of the voltage difference **268**. The second difference **324** corresponds to and has the same shape as a second derivative (d^2/dt^2) of the voltage difference **268**. The third difference **332** corresponds to and has the same shape as a third derivative (d^3/dt^3) of the voltage difference **268**. The fourth difference **340** corresponds to and has the same shape as a fourth derivative (d^4/dt^4) of the voltage difference **268**.

Additionally, minimum and maximum values of the first difference **316** occur at the same times as minimum and maximum values of the first derivative (d/dt) of the voltage difference **268**. Minimum and maximum values of the second difference **324** also occur at the same times as minimum and maximum values of the second derivative (d^2/dt^2) of the voltage difference **268**. Minimum and maximum values of the third difference **332** also occur at the same times as minimum and maximum values of the (d^3/dt^3) of the voltage difference **268**. Since the first-fourth differences **316**, **324**, **332**, and **340** are determined at a predetermined rate, the first-fourth differences **316**, **324**, **332**, and **340** are an accurate representative of the first-fourth derivatives. Additionally, using sums instead of averages reduces computational complexity and maintains the shape of the input signal.

While the example of calculating the first-fourth differences **316**, **324**, **332**, and **340** has been discussed, two or more differences may be determined, and a greater or lesser number of difference modules may be implemented. Also, while the example is discussed in terms of use of the voltage

difference **268**, the present application is applicable to identifying changes in other signals. While the example of calculating the first-fourth differences **316**, **324**, **332**, and **340** has been discussed, first-fourth derivatives may be determined based on the voltage difference **268** and used in place of the first-fourth differences **316**, **324**, **332**, and **340**.

A parameter determination module **344** determines the injector parameters **222** for the fuel injector **121** based on the voltage difference **268** and the third and fourth differences **332** and **340**. The parameter determination module **344** may determine the injector parameters **222** additionally or alternatively based on one or more other parameters.

FIG. **3** includes a graph including example traces of the voltage difference **268**, current **350** through the fuel injector **121**, the third difference **332**, the fourth difference **340**, and fuel flow **352** versus time for a fuel injection event. Referring now to FIGS. **2** and **3**, the injector driver module **236** applies a pulse to the fuel injector **121** from time **354** until time **358** for the fuel injection event. Current flows through the fuel injector **121** based on the application of the pulse to the fuel injector **121**, as illustrated by **350**.

The period between when the injector driver module **236** ends the pulse and when the fuel injector **121** reaches a fully closed state may be referred to as the closing period of the fuel injector **121**. A first zero crossing of the fourth difference **340** that occurs after the injector driver module **236** ends the pulse may correspond to the time when the fuel injector **121** reaches the fully closed state. In FIG. **3**, the fourth difference **340** first crosses zero at approximately time **362**. The closing period of the fuel injector **121** therefore corresponds to the period between time **358** and time **362** in FIG. **3**. The parameter determination module **344** determines the closing period of the fuel injector **121** based on the period between the time that the injector driver module **236** ends the pulse for a fuel injection event and the time that the fourth difference **340** first crosses zero after the end of the pulse.

The third difference **332** reaches a minimum value at the first zero crossing of the fourth difference **340**. The minimum value of the third difference **332** is indicated by **366** in FIG. **3**. The third difference **332** reaches a maximum value at a second zero crossing of the fourth difference **340** that occurs after the injector driver module **236** ends the pulse. In FIG. **3**, the second zero crossing of the fourth difference **340** occurs at approximately time **370**, and the maximum value of the third difference **332** is indicated by **374**.

In various implementations, a first predetermined offset may be applied to the first zero crossing to identify the minimum value of the third difference **332** and/or a second predetermined offset may be applied to the second zero crossing to identify the maximum value of the third difference **332**. For example, the minimum value of the third difference **332** may occur the first predetermined offset before or after the first zero crossing of the fourth difference **340** and/or the maximum value of the third difference **332** may occur the second predetermined offset before or after the second zero crossing of the fourth difference **340**. The application of the first and/or second predetermined offsets may be performed to better correlate with the minimum and maximum values of the third difference **332**.

The parameter determination module **344** determines an opening magnitude of the fuel injector **121** based on a difference between the minimum value **366** of the third difference **332** and the maximum value **374** of the third difference **332**.

Based on the closing period of the fuel injector **121** and the opening magnitude of the fuel injector **121**, the length of pulses applied to the fuel injector **121** can be adjusted such that the fuel injector **121** will as closely as possible inject the same amount of fuel as other fuel injectors, despite manufacturing differences between the fuel injectors. Adjustments are determined and applied for each fuel injector. Without the adjustments, the differences between the fuel injectors may cause the fuel injectors to inject different amounts of fuel.

The parameter determination module **344** may determine a closing period delta for the fuel injector **121** based on a difference between the closing period of the fuel injector **121** and a predetermined closing period. The predetermined closing period may be calibrated based on the closing periods of a plurality of fuel injectors. For example only, the parameter determination module **344** may set the closing period delta based on or equal to the predetermined closing period minus the closing period of the fuel injector **121**.

The parameter determination module **344** may determine a closing period compensation value based on the closing period delta and a closing period adjustment value. For example only, the parameter determination module **344** may set the closing period compensation value based on or equal to a product of the closing period delta and the closing period adjustment value.

The parameter determination module **344** may determine the closing period adjustment value based on the final pulse width **224** used for a fuel injection event and a fuel pressure **380** of the fuel injection event. The parameter determination module **344** may determine the closing period adjustment value, for example, using one of a function and a mapping that relates the final pulse width **224** and the fuel pressure **380** to the closing period adjustment value. The fuel pressure **380** corresponds to a pressure of the fuel provided to the fuel injector **121** for the fuel injection event and may be, for example, measured using the fuel pressure sensor **176**.

The parameter determination module **344** may determine an opening period adjustment value for the fuel injector **121** based on the final pulse width **224** used for a fuel injection event and a predetermined pulse width for the fuel injection event. For example only, the parameter determination module **344** may set the opening period adjustment value based on a difference between the final pulse width **224** for the fuel injection event and the predetermined pulse width for the fuel injection event. The parameter determination module **344** may, for example, set the opening period adjustment value based on or equal to the final pulse width **224** for the fuel injection event minus the predetermined pulse width for the fuel injection event.

The parameter determination module **344** may determine the predetermined pulse width for the fuel injection event based on the opening magnitude of the fuel injector **121** and the fuel pressure **380** for the fuel injection event. Determination of the opening magnitude of the fuel injector **121** is discussed above. The parameter determination module **344** may determine the predetermined pulse width, for example, using one of a function and a mapping that relates the opening magnitude and the fuel pressure **380** to the predetermined pulse width.

As stated above, the adjusting module **220** adjusts the initial pulse width **216** for a fuel injection event based on one or more of the injector parameters **222** to determine the final pulse width **224** for the fuel injection event. For example only, the adjusting module **220** may set the final pulse width **224** based on the initial pulse width **216**, the opening period compensation value, and the closing period compensation value. The adjusting module **220** may set the final pulse width **224**, for example, using one of a function and a

mapping that relates the initial pulse width **216**, the opening period compensation value, and the closing period compensation value to the final pulse width **224**. For example only, the adjusting module **220** may set the final pulse width **224** equal to or based on a sum of the initial pulse width **216**, the opening period compensation value, and the closing period compensation value. While the above example is discussed in terms of the fuel injector **121**, a respective opening period compensation value and a respective closing period compensation value may be determined and used for each fuel injector.

FIG. **4** is a flowchart depicting an example method of determining the first-fifth sums **276**, **284**, **292**, **300**, and **308** and the first-fourth differences **316**, **324**, **332**, and **340** for determining the closing period, the closing period compensation value, and the opening period compensation value for a fuel injection event of the fuel injector **121**. Control may begin with **404** where the parameter determination module **344** determines whether the injector driver module **236** has stopped applying a pulse to the fuel injector **121** for the fuel injection event. If **404** is true, the parameter determination module **344** may start a timer, and control continues with **408**. If **404** is false, control may remain at **404**.

At **408**, the voltage difference module **264** samples the high and low side voltages **262** and **263** and generates a value of the voltage difference **268** based on the samples. The parameter determination module **344** may also resets a sample counter value at **408**. At **412**, the parameter determination module **344** determines whether the sample counter value is less than N. As described above, N is the number values of used by the first summer module **272** to determine the first sum **276**. If **412** is true, control may return to **408**. If **412** is false, control continues with **416**.

At **416**, the first summer module **272** determines the first sum **276** based on the last N values of the voltage difference **268**. The second summer module **280** determines the second sum **284** based on the last M values of the first sum **276**. The third summer module **288** determines the third sum **292** based on the last M values of the second sum **284**. The fourth summer module **296** determines the fourth sum **300** based on the last M values of the third sum **292**. The fifth summer module **304** determines the fifth sum **308** based on the last M values of the fourth sum **300**.

Also at **416**, the first difference module **312** determines the first difference **316** between the fifth sum **308** and the last value of the fifth sum **308**. The second difference module **320** determines the second difference **324** between the first difference **316** and the last value of the first difference **316**. The third difference module **328** determines the third difference **332** between the second difference **324** and the last value of the second difference **324**. The fourth difference module **336** determines the fourth difference **340** between the third difference **332** and the last value of the third difference **332**. The parameter determination module **344** also increments an update counter value and resets the sample counter value at **416**.

At **420**, the parameter determination module **344** determines whether the update counter value is less than a predetermined value. If **420** is true, control returns to **408**. If **420** is false, control continues with **424**. The predetermined value is calibratable and is set based on the number of samples of the voltage difference **268** necessary to fill all of the following modules with new values: the first summer module **272**, the second summer module **280**, the third summer module **288**, the fourth summer module **296**, the fifth summer module **304**, the first difference module **312**, the second difference module **320**, the third difference module **328**, and the fourth difference module **336**. For example only, based on the example of FIG. **2**, the predetermined value may be set to greater than or equal to:

$$(N*M)+Q(N*(M-1))+N*R,$$

where N is the number of samples used by the first summer module **272**, M is the number of samples used by the second, third, fourth, and fifth summer modules **280**, **288**, **296**, and **304** (in the example where M=P=Q=R), K is the number of summer modules implemented that update their outputs each time the first summer module **272** updates the first sum **276**, and R is the number of difference modules implemented. In the example of FIG. **2**, Q equals 4 (for the second, third, fourth, and fifth summer modules **280**, **288**, **296**, and **304**), and R equals 4 (for the first, second, third, and fourth difference modules **312**, **320**, **328**, and **336**).

At **424**, the parameter determination module **344** may monitor the fourth difference **340** for the first zero crossing. The parameter determination module **344** may identify the minimum value of the third difference **332** as the value of the third difference **332** occurring at the first zero crossing of the fourth difference **340**. The parameter determination module **344** may also monitor the fourth difference for the second zero crossing. The parameter determination module **344** may identify the maximum value of the third difference **332** as the value of the third difference **332** occurring at the second zero crossing of the fourth difference **340**. While not explicitly shown, control continues to generate samples of the voltage difference **268** and to update the first, second, third, fourth, and fifth sums **276**, **284**, **292**, **300**, and **308** and the first, second, third, and fourth differences **316**, **324**, **332**, and **340** at **424** to determine the minimum and maximum values of the third difference **332**.

The parameter determination module **344** may determine closing period of the fuel injector **121** at **428**. The parameter determination module **344** may determine the closing period of the fuel injector **121** based on the timer value at the first zero crossing of the fourth difference **340**.

The parameter determination module **344** may also determine the opening period compensation value and the closing period compensation value for the fuel injector **121** at **428**. The parameter determination module **344** determines the opening magnitude of the fuel injector **121** based on a difference between the minimum value of the third difference **332** and the maximum value of the third difference **332**. The parameter determination module **344** may determine the closing period delta for the fuel injector **121** based on a difference between the closing period of the fuel injector **121** and the predetermined closing period. For example only, the parameter determination module **344** may set the closing period delta based on or equal to the predetermined closing period minus the closing period of the fuel injector **121**.

The parameter determination module **344** may determine the closing period compensation value based on the closing period delta and a closing period adjustment value. For example only, the parameter determination module **344** may set the closing period compensation value based on or equal to a product of the closing period delta and the closing period adjustment value. The parameter determination module **344** may determine the closing period adjustment value for the fuel injection event based on the final pulse width **224** used for a fuel injection event and the fuel pressure **380** for the fuel injection event. The parameter determination module **344** may determine the closing period adjustment value, for example, using one of a function and a mapping that relates the final pulse width **224** and the fuel pressure **380** to the closing period adjustment value.

The parameter determination module **344** may determine the opening period adjustment value for the fuel injector **121** based on the final pulse width **224** used for the fuel injection event and the predetermined pulse width for the fuel injection event. For example only, the parameter determination module **344** may set the opening period adjustment value based on a difference between the final pulse width **224** for the fuel injection event and the predetermined pulse width for the fuel injection event. The parameter determination module **344** may, for example, set the opening period adjustment value based on or equal to the final pulse width **224** for the fuel injection event minus the predetermined pulse width for the fuel injection event.

The parameter determination module **344** may determine the predetermined pulse width for the fuel injection event based on the opening magnitude of the fuel injector **121** and the fuel pressure **380** for the fuel injection event. The parameter determination module **344** may determine the predetermined pulse width, for example, using one of a function and a mapping that relates the opening magnitude and the fuel pressure **380** to the opening period adjustment value.

As stated above, the closing period compensation value and the opening period compensation value can be used to adjust the initial pulse width **216** determined for future fuel injection events.

FIG. **5** is a flowchart depicting an example method of controlling fueling for a fuel injection event of the fuel injector **121**. Control may begin with **504** where the pulse width module **212** determines the initial pulse width **216** for a fuel injection event of the fuel injector **121**. The pulse width module **212** may determine the initial pulse width **216** based on the target mass determined for the fuel injection event, which may be determined based on a target air/fuel mixture and a mass of air expected to be within the cylinder **114**.

At **508**, the adjusting module **220** adjusts the initial pulse width **216** based on the opening period compensation value and the closing period compensation value to produce the final pulse width **224**. For example, the adjusting module **220** may set the final pulse width **224** equal to or based on a sum of the initial pulse width **216**, the opening period compensation value, and the closing period compensation value. At **512**, the injector driver module **236** applies power to the fuel injector **121** based on the final pulse width **224**. The application of power to the fuel injector **121** should cause the fuel injector **121** to open and inject fuel for the fuel injection event.

Referring back to FIG. **2**, a diagnostic module **390** diagnoses missed fueling events of the fuel injector **121**. A missed fueling event may refer to a fuel injection event of a fuel injector where the fuel injector failed to open in response to the application of power to the fuel injector. Missed fueling events may be more likely to occur when a fuel injector is to perform multiple shorter fuel injection events per combustion cycle.

The diagnostic module **390** determines whether a missed fueling event occurred based on the opening magnitude determined for a fuel injection event of the fuel injector **121**. The diagnostic module **390** determines a predetermined opening magnitude for the fuel injection event based on the fuel pressure **380** of the fuel injection event. The predetermined opening magnitude may correspond to a minimum opening magnitude where the fuel injector **121** opened and injected fuel during the fuel injection event. An opening magnitude of greater than the predetermined opening magnitude may indicate that the fuel injector **121** opened and injected fuel. An opening magnitude of less than the predetermined opening magnitude may indicate that the fuel injector **121** failed to open and did not inject fuel.

The diagnostic module **390** may indicate the occurrence of a missed fueling event when the opening magnitude of a fuel injection event is less than the predetermined opening magnitude of the fuel injection event. Conversely, the diagnostic module **390** may indicate that the fuel injection event was successful when the opening magnitude is greater than the predetermined opening magnitude.

The diagnostic module **390** may diagnose a missed fueling fault with the fuel injector **121** when one or more missed fueling events occur for the fuel injector **121**. For example only, the diagnostic module **390** may diagnose a missed fueling fault with the fuel injector **121** when at least X missed fueling events are diagnosed during Y fuel injection events of the fuel injector **121**. X and Y are predetermined values that are integers greater than zero, and Y is less than or equal to X.

The diagnostic module **390** may take one or more remedial actions when a missed fueling fault is diagnosed. For example, the diagnostic module **390** may set a predetermined diagnostic trouble code (DTC) in memory. The predetermined DTC may be indicative of the occurrence of a missed fueling fault with the fuel injector **121**. The diagnostic module **390** may additionally illuminate a malfunction indicator lamp (MIL) **394** when a missed fueling fault is diagnosed. The diagnostic module **390** may additionally or alternatively perform one or more other remedial actions when a missed fueling fault is diagnosed, such as disabling the use of multiple fuel injection events per combustion cycle and limiting the number of fuel injection events per combustion cycle to one. Other ways to detect missed fueling events, such as based on engine speed, may be unable to detect missed fueling events when multiple fuel injection events are performed per combustion cycle.

While the present application is discussed in terms of diagnosing missed fueling events of the fuel injector **121**, the present application is more generally applicable to diagnosing failure of a solenoid to open in response to an application of power. For example, the present application is applicable to diagnosing the failure to open of an oil control solenoid (e.g., for variable valve actuation), diesel fuel injectors, pressure control solenoids, and other types of solenoids.

FIG. **6** includes a method of determining whether a fuel injector injected fuel for a fuel injection event. Control may begin with **604** where the parameter determination module **344** determines whether the injector driver module **236** has completed the application of a pulse to the fuel injector **121** for a fuel injection event. If **604** is true, control continues with **608**. If **604** is false, control may remain at **604**.

At **608**, the parameter determination module **344** determines the opening magnitude of the fuel injector **121** for the fuel injection event. The parameter determination module **344** may determine the opening magnitude based on a difference between the minimum and maximum values of the third difference **332**, as discussed above.

The diagnostic module **390** determines the predetermined opening magnitude for the fuel injection event at **612** based on the fuel pressure **380** of the fuel injection event. For example only, the diagnostic module **390** may determine the predetermined opening magnitude using one of a function and a mapping that relates the fuel pressure **380** to the predetermined opening magnitude.

At **616**, the diagnostic module **390** determines whether the opening magnitude of the fuel injection event is less than the predetermined opening magnitude of the fuel injection

event. If **616** is false, the diagnostic module **390** may indicate that fuel was successfully injected during the fuel injection event at **620**, and control may end. If **616** is true, the diagnostic module **390** may indicate that a missed fueling event occurred at **624**. In other words, the diagnostic module **390** may indicate that no fuel was injected during the fuel injection event at **624**. While the example of FIG. **6** is shown and discussed as ending after **620** or **624**, control may return to **604** for a next fuel injection event. Also, while the example of FIG. **6** is discussed in conjunction with the fuel injector **121**, FIG. **6** is also applicable to the other fuel injectors of the engine **102**, and missed fueling event may be diagnosed for each fuel injector.

FIG. **7** is a flowchart depicting an example method of diagnosing a missed fueling fault with the fuel injector **121**. Control begins with **704** where the diagnostic module **390** resets a total counter and a missed fueling event counter. At **708**, the parameter determination module **344** determines whether the injector driver module **236** has applied a pulse to the fuel injector **121** for a fuel injection event. If **708** is true, control continues with **712**. If **708** is false, control may remain at **708**. The diagnostic module **390** increments the total counter at **712**. In this manner, the value of the total counter tracks the total number of fueling events that have occurred since the total counter was last reset.

At **716**, the parameter determination module **344** determines the opening magnitude of the fuel injector **121** for the fuel injection event. The parameter determination module **344** may determine the opening magnitude based on a difference between the minimum and maximum values of the third difference **332**, as discussed above.

The diagnostic module **390** determines the predetermined opening magnitude for the fuel injection event at **720** based on the fuel pressure **380** of the fuel injection event. For example only, the diagnostic module **390** may determine the predetermined opening magnitude using one of a function and a mapping that relates the fuel pressure **380** to the predetermined opening magnitude.

At **724**, the diagnostic module **390** determines whether the opening magnitude of the fuel injection event is less than the predetermined opening magnitude of the fuel injection event. If **724** is true, the diagnostic module **390** may indicate that a missed fueling event occurred and increment the missed fueling event counter at **728**, and control may continue with **732**. In other words, the diagnostic module **390** may indicate that no fuel was injected during the fuel injection event at **728**. If **724** is false, the diagnostic module **390** may indicate that fuel was successfully injected during the fuel injection event, and control may continue with **732**.

At **732**, the diagnostic module **390** may determine whether the value of the missed fueling event counter is less than a first predetermined value (X). If **732** is false, the diagnostic module **390** may indicate the presence of a missed fueling fault with the fuel injector **121** at **736**, and control may end. The diagnostic module **390** may take one or more other remedial actions at **736**, such as setting a predetermined DTC indicative of a missed fueling fault with the fuel injector **121** and/or illuminating the MIL **394**. If **732** is true, control may continue with **740**. At **740**, the diagnostic module **390** may determine whether the value of the total counter is less than a second predetermined value (Y) that is greater than or equal to the first predetermined value (X). If **740** is true, control may return to **708** for a next fuel injection event of the fuel injector **121**. If **740** is false, control may end.

While the example of FIG. **7** is shown and discussed as ending, control may return to **704** to start over. Also, while the example of FIG. **7** is discussed in conjunction with the fuel injector **121**, FIG. **7** is also applicable to the other fuel injectors of the engine **102**, and missed fueling faults may be diagnosed for each fuel injector.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

In this application, including the definitions below, the term module may be replaced with the term circuit. The term module may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; memory (shared, dedicated, or group) that stores code executed by a processor; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared processor encompasses a single processor that executes some or all code from multiple modules. The term group processor encompasses a processor that, in combination with additional processors, executes some or all code from one or more modules. The term shared memory encompasses a single memory that stores some or all code from multiple modules. The term group memory encompasses a memory that, in combination with additional memories, stores some or all code from one or more modules. The term memory may be a subset of the term computer-readable medium. The term computer-readable medium does not encompass transitory electrical and electromagnetic signals propagating through a medium, and may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory tangible computer readable medium include nonvolatile memory, volatile memory, magnetic storage, and optical storage.

The apparatuses and methods described in this application may be partially or fully implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on at least one non-transitory tangible computer readable medium. The computer programs may also include and/or rely on stored data.

What is claimed is:

1. A fuel control system for a vehicle, comprising:

an injector driver module that applies power to a fuel injector of an engine for a first fuel injection event;

a voltage measuring module that measures first and second voltages at first and second electrical connectors of the fuel injector;

a parameter determination module that determines a maximum value based on a first difference between the

first and second voltages, that determines a minimum value based on the first difference between the first and second voltages, and that determines a second difference between the maximum and minimum values; and

a diagnostic module that, based on the second difference between the maximum and minimum values, indicates whether the fuel injector injected fuel in response to the application of power,

wherein the injector driver module applies power to the fuel injector for a second fuel injection event of the fuel injector based on the second difference between the maximum and minimum values.

2. The fuel control system of claim **1** wherein the diagnostic module determines a predetermined value based on a fuel pressure of the first fuel injection event and determines whether the fuel injector injected fuel in response to the application of power based on a comparison of the predetermined value with the second difference between the maximum and minimum values.

3. The fuel control system of claim **2** wherein the diagnostic module indicates that the fuel injector did not inject fuel in response to the application of power when the second difference between the maximum and minimum values is less than the predetermined value.

4. The fuel control system of claim **3** wherein the diagnostic module indicates that the fuel injector injected fuel in response to the application of power when the second difference between the maximum and minimum values is greater than the predetermined value.

5. The fuel control system of claim **1** wherein the diagnostic module selectively illuminates a malfunction indicator lamp (MIL) when the fuel injector did not inject fuel in response to the application of power.

6. The fuel control system of claim **1** wherein the diagnostic module stores a predetermined diagnostic trouble code (DTC) in memory when the fuel injector did not inject fuel in response to the application of power.

7. The fuel control system of claim **1** further comprising:

a first summer module that determines a first sum of (i) the first difference between the first and second voltages and (ii) N previous values of the first difference between the first and second voltages, wherein N is an integer greater than or equal to one;

a second summer module that determines a second sum of (i) the first sum and (ii) M previous values of the first sum, wherein M is an integer greater than or equal to one;

a first difference module that determines a third difference between (i) the second sum and (ii) a previous value of the second sum;

a second difference module that determines a fourth difference between (i) the third difference and (ii) a previous value of the third difference;

a third difference module that determines a fifth difference between (i) the fourth difference and (ii) a previous value of the fourth difference; and

a fourth difference module that determines a sixth difference between (i) the fifth difference and (ii) a previous value of the fifth difference,

wherein the parameter determination module determines the maximum value of the third difference and the minimum value of the third difference and determines the second difference between the maximum and minimum values of the third difference.

8. The fuel control system of claim **7** wherein the parameter determination module determines the minimum value of the third difference based on a first zero-crossing of the fourth difference.

9. The fuel control system of claim **8** wherein the parameter determination module determines the maximum value of the third difference based on a second zero-crossing of the fourth difference.

10. A control system for a vehicle, comprising:

a driver module that applies power to an actuator including a solenoid for a first opening event;

a voltage measuring module that measures first and second voltages at first and second electrical connectors of the actuator;

a parameter determination module that determines a maximum value based on a first difference between the first and second voltages at a first time, that determines a minimum value based on the first difference between the first and second voltages at a second time, and that determines a second difference between the maximum and minimum values; and

a diagnostic module that, based on the second difference between the maximum and minimum values, indicates whether the solenoid opened in response to the application of power,

wherein the driver module applies power to the actuator for a second opening event of the actuator based on the second difference between the maximum and minimum values.

11. A fuel control method for a vehicle, comprising:

applying power to a fuel injector of an engine for a first fuel injection event;

measuring first and second voltages at first and second electrical connectors of the fuel injector;

determining a maximum value based on a first difference between the first and second voltages at a first time;

determining a minimum value based on the first difference between the first and second voltages at a second time;

determining a second difference between the maximum and minimum values;

based on the second difference between the maximum and minimum values, indicating whether the fuel injector injected fuel in response to the application of power; and

applying power to the fuel injector for a second fuel injection event of the fuel injector based on the second difference between the maximum and minimum values.

12. The fuel control method of claim **11** further comprising:

determining a predetermined value based on a fuel pressure of the first fuel injection event; and

determining whether the fuel injector injected fuel in response to the application of power based on a comparison of the predetermined value with the second difference between the maximum and minimum values.

13. The fuel control method of claim **12** further comprising indicating that the fuel injector did not inject fuel in response to the application of power when the second difference between the maximum and minimum values is less than the predetermined value.

14. The fuel control method of claim **13** further comprising indicating that the fuel injector injected fuel in response to the application of power when the second difference between the maximum and minimum values is greater than the predetermined value.

15. The fuel control method of claim 11 further comprising selectively illuminating a malfunction indicator lamp (MIL) when the fuel injector did not inject fuel in response to the application of power.

16. The fuel control method of claim 11 further comprising storing a predetermined diagnostic trouble code (DTC) in memory when the fuel injector did not inject fuel in response to the application of power.

17. The fuel control method of claim 11 further comprising:

determining a first sum of (i) the first difference between the first and second voltages and (ii) N previous values of the first difference between the first and second voltages, wherein N is an integer greater than or equal to one;

determining a second sum of (i) the first sum and (ii) M previous values of the first sum, wherein M is an integer greater than or equal to one;

determining a third difference between (i) the second sum and (ii) a previous value of the second sum;

determining a fourth difference between (i) the third difference and (ii) a previous value of the third difference;

determining a fifth difference between (i) the fourth difference and (ii) a previous value of the fourth difference;

determining a sixth difference between (i) the fifth difference and (ii) a previous value of the fifth difference;

determining the maximum value of the third difference and the minimum value of the third difference; and

determining the second difference between the maximum and minimum values of the third difference.

18. The fuel control method of claim 17 further comprising determining the minimum value of the third difference based on a first zero-crossing of the fourth difference.

19. The fuel control method of claim 18 further comprising determining the maximum value of the third difference based on a second zero-crossing of the fourth difference.

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